Variable Volume Fan Curve Coefficient Comparison

This measure changes the polynomial curve coefficients and minimum fan power that define the fan power performance curve for Fan:VariableSpeed objects in EnergyPlus.

Curve coefficients come from ASHRAE Standard 90.1-2016 Performance Rating Method Reference Manual Table 50 Fan Curve Default Values (identical to ASHRAE 90.1-2010 PRM Reference Manual Table 47) [1]. The OpenStudio default is "***Multi-zone VAV with static pressure reset***", which is the ASHRAE 90.1 PRM baseline for systems 5-8. The ASHRAE 90.1 PRM baseline for system 11 is "***Single zone VAV fan"*** representing a perfect static pressure reset. The ASHRAE 90.1 Appendix G Table G3.1.3.15 default is "***Multi Zone VAV with VSD and fixed SP setpoint***", which assumes no static pressure reset, and is sourced separately [4] (identical across ASHRAE 90.1-2007,2010,2013,2016). **Note that the ASHRAE 90.1 PRM baseline is the OpenStudio default and is different from the ASHRAE 90.1 Appendix G baseline**.

The OpenStudio default is identical to the "***Good SP Reset VSD Fan***" originally sourced from a 2003 California Energy Commission report, "Advanced Variable Air Volume System Design Guide" Appendix 5 - DOE-2 Fan Curves [2], which were created by Jeff Stein and Mark Hydeman from their fan curve model, detailed in "Development and Testing of the Characteristic Curve Fan Model" ASHRAE Transactions. 2004, Vol. 110 Issue 1, p347-356. 10p. [3]. This measure also includes curve coefficients for "***No SP Reset VSD Fan***", "***Typical VSD Fan***", and "***Perfect SP Reset VSD Fan***" (identical to "***Single zone VAV fan***") as detailed in the 2003 CEC report.

Fan power is calculated as the Part Load Ratio (PLR) times rated fan power. PLR is greater of:

PLR = A + B*FanRatio + C*FanRatio^2 + D*FanRatio^3

PLR = PowerMin

PLR = Ratio of fan power at part load conditions to full load fan power
PowerMin = Minimum fan power ratio
FanRatio = Ratio of air flow rate at part-load to full load air flow rate in cfm
A,B,C,D = Coefficients for the fan power curve

Sources:

- [1] PNNL, "BuildingsANSI/ASHRAE/IES Standard 90.1-2016 Performance Rating Method Reference Manual," September 2017.
- [2] California Energy Commision, "Advanced Variable Air Volume System Design Guide," October 2003.
- [3] - Jeff Stein and Mark Hydeman, "Development and Testing of the Characteristic Curve Fan Model," ASHRAE Transactions. 2004, Vol. 110 Issue 1, p347-356. 10p. Available online at (http://www.taylor-engineering.com/Websites/taylorengineering/articles/ASHRAE_Symposium_AN-04-3-1_Characteristic_Curve_Fan_Model.pdf)
- [4] ANSI/ASHRAE/IES Standard 90.1-2016 - Energy Standard for Buildings Except Low-Rise Residential

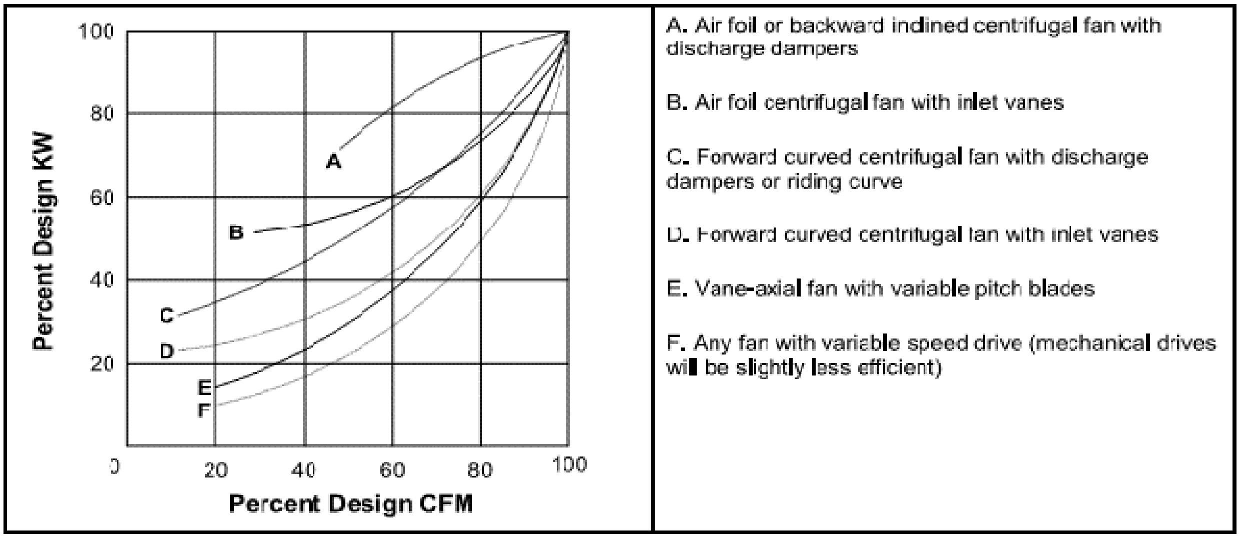
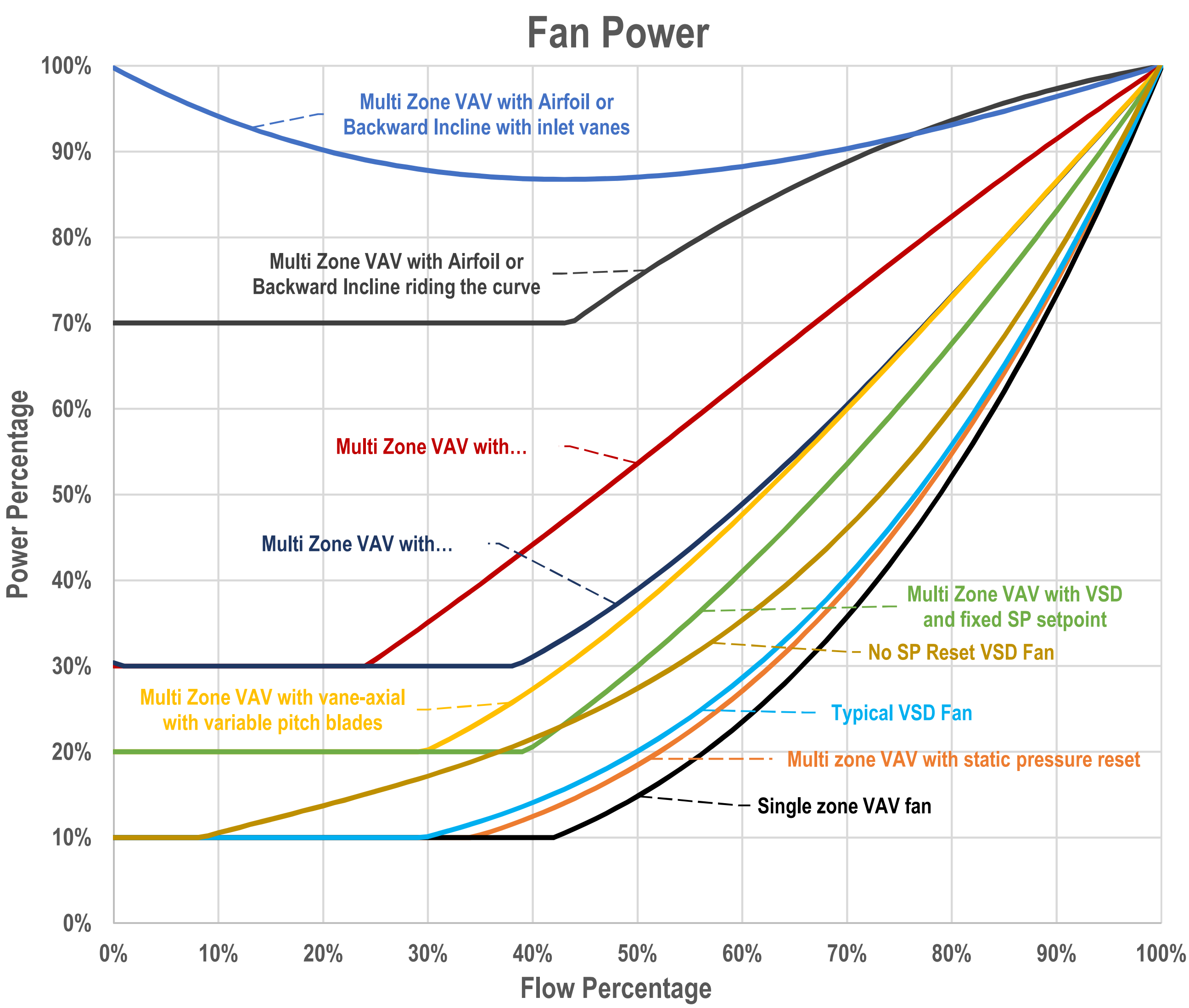


Figure 4-18 – VAV Fan Performance Curve

California Energy Commission, "2016 Nonresidential Compliance Manual," November 2015.



PNNL-26917

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ANSI/ASHRAE/IES Standard 90.1-2016 Performance Rating Method Reference Manual

S Goel

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September 2017

U.S. DEPARTMENT OF ENERGY

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Fan Position

Applicability	All supply fans
Definition	The position of the supply fan relative to the cooling coil. The configuration is either draw through (fan is downstream of the coil) or blow through (fan is upstream of the coil).
Units	List (see above)
Input Restrictions	As designed
Baseline Building	Draw through

Motor Position

Applicability	All supply fans
Definition	The position of the supply fan motor relative to the cooling air stream. The choices are: in the air stream or out of the air stream.
Units	List (see above)
Input Restrictions	As designed
Baseline Building	In the air stream

Fan Part-Flow Power Curve

Applicability All variable flow fan systems

Definition A part-load power curve that represents the percentage full-load power draw of the supply fan as a function of the percentage full-load airflow. The curve is typically represented as a cubic equation with an absolute minimum power draw specified.

Units Unitless ratio

Input Restrictions The fan curve shall be selected from Equation (11) and Table 50 for the type of fan specified in the proposed design.

$$\begin{aligned} &\textit{Greater of} \\ &PLR = a + b \cdot FanRatio + c \cdot FanRatio^2 + d \cdot FanRatio^3 \\ &PLR = PowerMin \end{aligned} \tag{11}$$

Where:

PLR	=	Ratio of fan power at part load conditions to full load fan power
PowerMin	=	Minimum fan power ratio
FanRatio	=	Ratio of cfm at part-load to full-load cfm
a, b, c and *d*	=	Constants from Table 50

Table 50. Fan Curve Default Values

Fan Type - Control Type	A	B	c	d	$\%Power_{Min}$
Multi Zone VAV with Airfoil (AF) or Backward Incline (BI) riding the curve[(a)]	0.1631	1.5901	-0.8817	0.1281	70%
Multi Zone VAV with AF or BI with inlet vanes[(a)]	0.9977	-0.659	0.9547	-0.2936	50%
Multi Zone VAV with Forward Curved (FC) fans riding the curve[(a)]	0.1224	0.612	0.5983	-0.3334	30%
Multi Zone VAV with FC with inlet vanes[(a)]	0.3038	-0.7608	2.2729	-0.8169	30%
Multi Zone VAV with vane-axial with variable pitch blades[(a)]	0.1639	-0.4016	1.9909	-0.7541	20%
Multi Zone VAV with VSD and fixed SP setpoint[(b)]	0.0013	0.1470	0.9506	-0.0998	20%
Multi zone VAV with static pressure reset[(c)]	0.04076	0.0881	-0.0729	0.9437	10%
Single zone VAV fan[(d)]	0.027828	0.026583	-0.087069	1.030920	10%

Data Sources:

(a) ECB Compliance Supplement, public review draft, Version 1.2, March 1996, but adjusted to be relatively consistent with the curve specified in the PRM.

(b) The fan curve for VSD is specified in Table G3.1.3.15.

(c) This is the good SP reset VSD fan curve from the advanced VAV design guide used for MZVAV systems.

(d) This is the perfect SP reset VSD fan curve from the advanced VAV design guide used for SZVAV systems.

http://www.energy.ca.gov/2003publications/CEC-500-2003-082/CEC-500-2003-082-A-11.PDF

Baseline Building Not applicable for baseline building systems 1 through 4. Baseline systems 5 through 8 will use the curve for "Multi zone VAV with fixed static pressure setpoint" curve. System 11 shall use the "Single zone VAV fan" curve. Constant volume fans are used for systems 9, 10, 12, and 13 and hence the descriptor is not applicable.

Supply Fan Power Index (kW/cfm)

Applicability Fan systems that use the power-per-unit-flow method

Definition The supply fan power per unit of flow

Units kW/cfm

Input Restrictions As designed or specified in the manufacturers' literature

Baseline Building Applicable when the baseline building uses the power-per-unit-flow method. Fan power is determined using Table 46 of this document. This power is then multiplied by the supply fan ratio.

CALIFORNIA ENERGY COMMISSION

Advanced Variable Air Volume System Design Guide

DESIGN GUIDELINES

October 2003
500-03-082-A-11

Gray Davis, *Governor*

Appendix 5 – DOE-2 Fan Curves

Created by Jeff Stein 5-5-03

These fan curves were developed using the Characteristic System Curve Fan Model developed by Stein and Hydeman.

Curves include part load performance of the fan, belt, motor, and VSD

This is based on a plenum airfoil fan on a system curve through 0.7"

```
"Typical VSD Fan" = CURVE-FIT
TYPE           = CUBIC
INPUT-TYPE      = COEFFICIENTS
OUTPUT-MIN      = 0
 OUTPUT-MAX      = 1
COEFFICIENTS    = (0.047182815, 0.130541742, -0.117286942,
0.940313747)
      . .
```

This is based on a plenum airfoil fan on a system curve through 0"

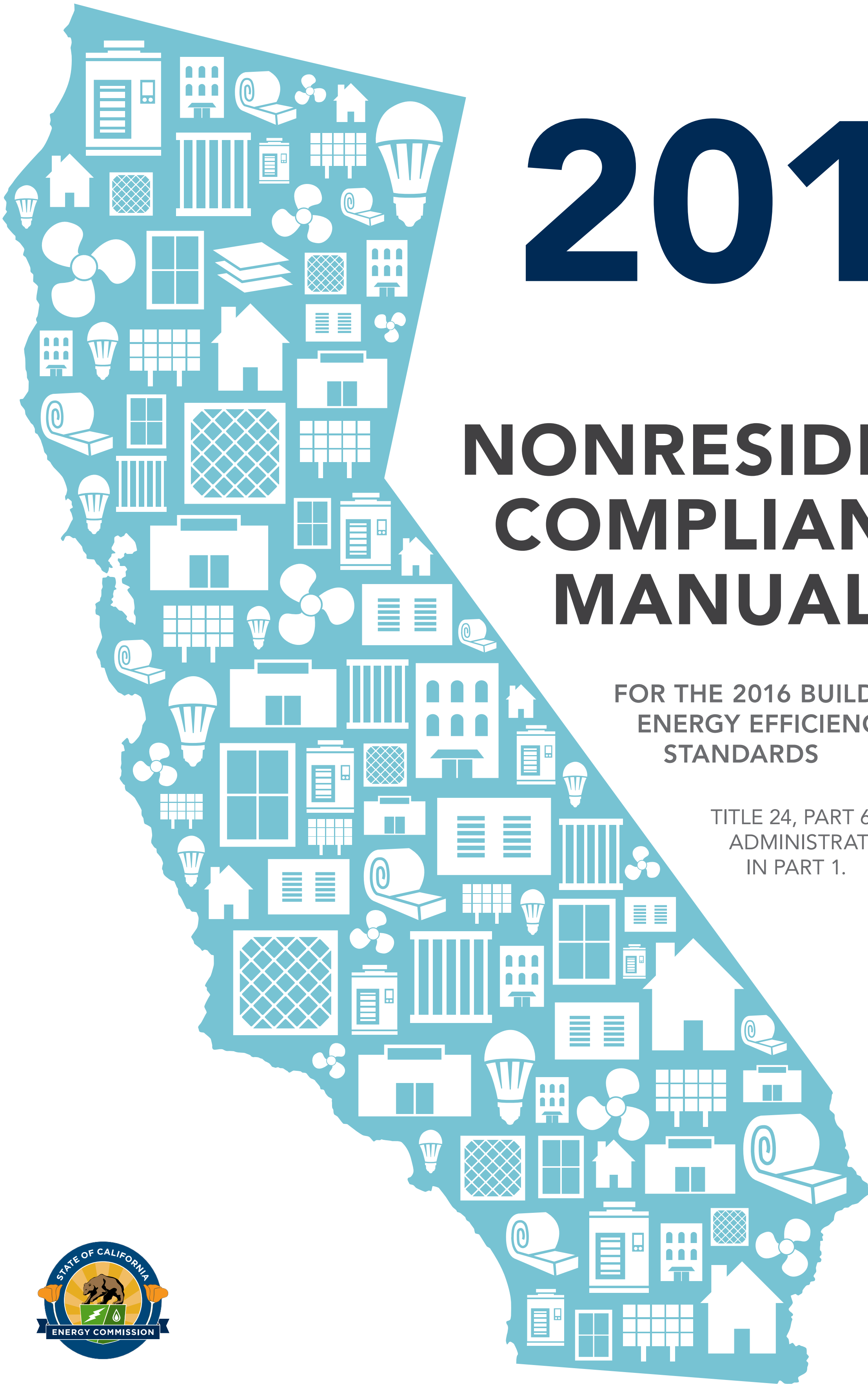
```
"Perfect SP Reset VSD Fan" = CURVE-FIT
  TYPE           = CUBIC
  INPUT-TYPE      = COEFFICIENTS
  OUTPUT-MIN      = 0
  OUTPUT-MAX      = 1
  COEFFICIENTS    = (0.027827882, 0.026583195, -0.0870687, 1.03091975)
  ..
```

This is based on a plenum airfoil fan on a system curve through 0.5"

```
"Good SP Reset VSD Fan" = CURVE-FIT
  TYPE           = CUBIC
  INPUT-TYPE      = COEFFICIENTS
  OUTPUT-MIN      = 0
  OUTPUT-MAX      = 1
  COEFFICIENTS    = (0.040759894, 0.08804497, -0.07292612, 0.943739823)
  ..
```

This is based on a plenum airfoil fan on a system curve through 1.5"

```
"No SP Reset VSD Fan" = CURVE-FIT
  TYPE          = CUBIC
  INPUT-TYPE      = COEFFICIENTS
  OUTPUT-MIN      = 0
  OUTPUT-MAX      = 1
  COEFFICIENTS    = (0.070428852, 0.385330201, -0.460864118,
1.00920344)
  ..
Plenum 0"       (0.027827882, 0.026583195, -0.0870687, 1.03091975)
Plenum 0.3"     (0.034171263, 0.059448041, -0.061049511, 0.966140782)
Plenum 0.4"     (0.037442571, 0.072000619, -0.062564426, 0.952238103)
Plenum 0.5"     (0.040759894, 0.08804497, -0.07292612, 0.943739823)
Plenum 0.6"     (0.044034586, 0.107518462, -0.091288825, 0.939910504)
Plenum 0.7"     (0.047182815, 0.130541742, -0.117286942, 0.940313747)
Plenum 0.8"     (0.050254136, 0.156227953, -0.148857337, 0.943697119)
Plenum 1.0"     (0.056118534, 0.214726686, -0.226093052, 0.957646288)
Plenum 1.5"     (0.070428852, 0.385330201, -0.460864118, 1.00920344)
```



2016

NONRESIDENTIAL COMPLIANCE MANUAL

FOR THE 2016 BUILDING ENERGY EFFICIENCY STANDARDS

TITLE 24, PART 6, AND ASSOCIATED ADMINISTRATIVE REGULATIONS IN PART 1.

STATE OF CALIFORNIA
ENERGY COMMISSION

NOVEMBER 2015
CEC-400-2015-033-CMF

CALIFORNIA ENERGY COMMISSION
Edmund G. Brown Jr., Governor

Example 4-36

Question

If my design conditions are 94°Fdb/82°Fwb can I use my design cooling loads to size a water-side economizer?

Answer

No. The design cooling load calculations must be rerun with the outdoor air temperature set to 50°Fdb/45°Fwb. The specified tower, as well as cooling coils and other devices, must be checked to determine if it has adequate capacity at this lower load and wet-bulb condition.

Example 4-37

Question

Will a strainer cycle water-side economizer meet the prescriptive economizer requirements? (Refer to Figure 4-33)

Answer

No. It cannot be integrated to cool simultaneously with the chillers.

Example 4-38

Question

Does a 12 ton packaged AC unit in climate zone 10 need an economizer?

Answer

Yes and the economizer must be equipped with an economizer fault detection and diagnostic system. However the requirement for an economizer can be waived if the AC unit's efficiency is greater than or equal to an EER of 14.3. Refer to Table 4-18

4.5.2.3 VAV Supply Fan Controls

§140.4(c)2 and §140.4(m)

Both single and multiple zone systems are required to have VAV supply based on the system type as described in Table 4-21. The VAV requirements for supply fans are as follows:

1. Single zone systems (where the fans are controlled directly by the space thermostat) shall have a minimum of 2 stages of fan speed with no more than 66 percent speed when operating on stage 1 while drawing no more than 40 percent full fan power when running at 66 percent speed.
2. All systems with air-side economizers to satisfy Section 4.5.2.2 are required to have a minimum of 2 speeds of fan control during economizer operation.
3. Multiple zone systems shall limit the fan motor demand to no more than 30 percent of design wattage at 50 percent design air volume.

Variable speed drives can be used to meet any of these three requirements.

Actual fan part load performance, available from the fan manufacturer, should be used to test for compliance with item 3 above. Figure 4-25 shows typical performance curves for different types of fans. As can be seen, both air foil fans and backward inclined fans using either discharge dampers or inlet vanes consume more than 30 percent power at 50 percent flow when static pressure set point is one-third of total design static pressure using certified manufacturer's test data. These fans will not normally comply with these requirements unless a variable speed drive is used.

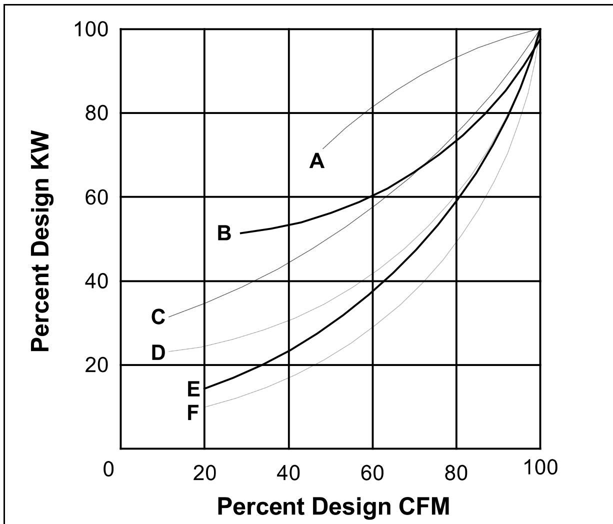
VAV fan systems that don't have DDC to the zone level are required to have the static pressure sensor located in a position such that the control setpoint is ≤1/3 of the design static pressure of the fan. For systems without static pressure reset the further the sensor is from the fan the more energy will be saved. For systems with multiple duct branches in the distribution you must provide separate sensors in each branch and control the fan to satisfy the sensor with the greatest demand. When locating sensors, care should be taken to have at least one sensor between the fan and all operable dampers (e.g. at the bottom of a supply shaft riser before the floor fire/smoke damper) to prevent loss of fan static pressure control.

For systems with DDC to the zone level the sensor(s) may be anywhere in the distribution system and the duct static pressure setpoint must be reset by the zone demand. Typically this is done by one of the following methods:

1. Controlling so that the most open VAV box damper is 95 percent open.
2. Using a "trim and respond" algorithm to continually reduce the pressure until one or more zones indicate that they are unable to maintain airflow rate setpoints.
3. Other methods that dynamically reduce duct static pressure setpoint as low as possible while maintaining adequate pressure at the VAV box zone(s) of greatest demand.

Reset of supply pressure by demand not only saves energy but it also protects fans from operation in surge at low loads. Chapter 13, Acceptance Requirements, describes mandated acceptance test requirements for VAV system fan control.

Figure 4-25: VAV Fan Performance Curve



A. Air foil or backward inclined centrifugal fan with discharge dampers

B. Air foil centrifugal fan with inlet vanes

C. Forward curved centrifugal fan with discharge dampers or riding curve

D. Forward curved centrifugal fan with inlet vanes

E. Vane-axial fan with variable pitch blades

F. Any fan with variable speed drive (mechanical drives will be slightly less efficient)